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Observations of Energy Dissipation in the Wake of a Western Pacific Typhoon

Louis St. Laurent
Dept. of Oceanography
Florida State University, Tallahassee, FL

Now at
Dept. of Physical Oceanography
Woods Hole Oceanographic Institution
Woods Hole, MA
phone: (508) 289-2753, fax: (508) 457-2181, email: lous@whoi.edu

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LONG-TERM GOALS

We are focused on understanding small-scale processes that influence the ocean's thermodynamic and dynamic properties on the sub-mesoscale (scales less than 10 km). This includes the turbulent evolution of cold wakes caused by typhoons, and the subsequent mixing processes the restore the upper ocean stratification after a storm event.

OBJECTIVES

I propose to investigate the energy dissipation properties of the mixed layer and mixed-layer base / thermocline transition layer during direct forcing by a typhoon. It is hypothesized that inertial energy loss occurs not only through dissipative processes in the mixed layer, but also through dissipation occurring well into the transition layer between the mixed-layer base and the thermocline, where shear is enhanced. Energy is also lost to the thermocline by conversion of inertial energy into near-inertial wave radiation. The turbulence generated at in the transition layer is tied to shear instability occurring below the mixed-layer base, which appears to be a key mechanism in parameterizations for mixed-layer response to strong wind forcing.

Energy dissipation will be measured using a glider equipped with turbulence probes. A Slocum glider system from Webb Research will be adapted for this purpose. This is a novel instrument system, which will allow for turbulence measurements in a manner not previously possible.

APPROACH

To overcome the limitations of conventional microstructure profiling, we will use the recently developed turbulence glider system developed between the co-PI (St. Laurent), Rockland Scientific,

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and Webb Research. Considerable effort was spent in the past year developing and testing this new system. Here, I will describe the primary testing to date.

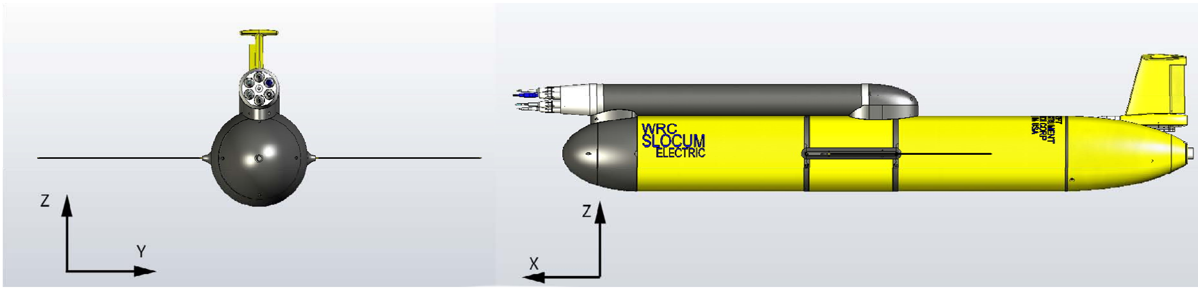

Figure 1: Schematic of Slocum electric glider, front view (left) and portside view (right).

Our Our glider is a Teledyne Webb Research Slocum Electric Glider with a depth rating of 200 m, shown in Figure 1. Slocum gliders have been in oceanographic use for approximately a decade, and their engineering and science capabilities are described in the literature (e.g., Webb et al. 2001; Schofield et al. 2007). Our system is of the Mach II variety, released in 2009, most notably featuring a redesigned tail section and digifin. It is a factory standard electric glider with navigation and communication modules, and a Seabird CTD system. The single nonstandard component of the system is the turbulence package: a microRider-1000-6 developed by Rockland Scientific Inc (Fig. 2). This package is a modular unit, suitable for mounting onto the Slocum or other AUV platforms. It is neutrally buoyant and supports two velocity shear probes (Osborn and Crawford, 1980), two FP07 thermistors, and one SBE7 micro-conductivity probe. These turbulence sensors are mounted on the tapered nose section of the package. Three accelerometers are mounted in an orthogonal configuration on the rear of the bulkhead that separates the nose section from the main pressure housing. The bulkhead also houses the port that connects to a pressure transducer. The main housing contains the signal condition electronics and the data acquisition computer (Persistor CF2).

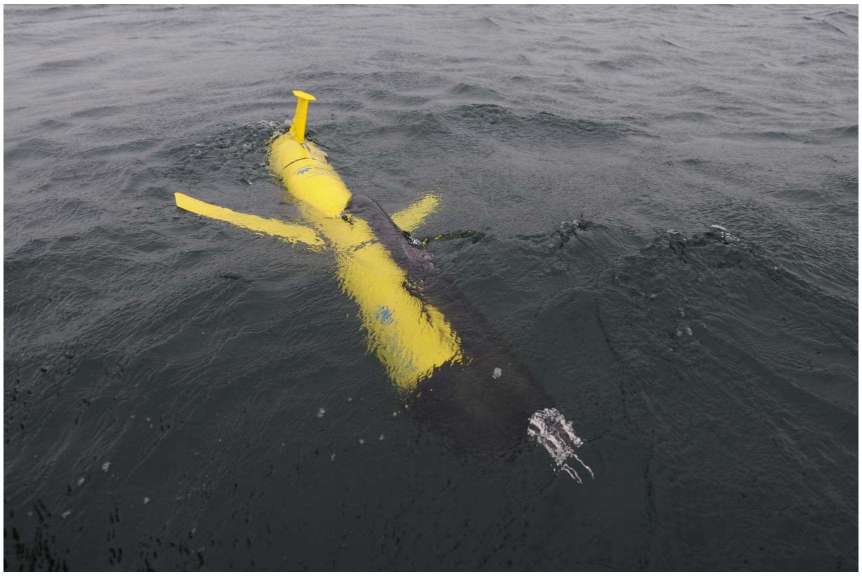

Figure 2: Photograph of the turbulence glider during its initial test in Ashumet Pond. The microrider package, built by Rockland Scientific, can be seen along the top of the glider. The specialized probes for measuring microstructure are visible protruding past the nose of the instrument.

Our instrument tests of the fully operational system were conducted during 28 April and 1 May 2009, in Ashumet Pond (N41^{o} 38'2.4", W70^{o} 32'5.3"), a small lake near East Falmouth, MA, which is frequently used by Teledyne Webb Research to test gliders. The lake measures ~1350 m north-south by ~900 m east-west and has a maximum depth of 20 m. The lack of surface inflow and outflow results in extremely low turbulence levels in the hypolimnion, which makes the lake an ideal site to test the noise level of the glider in terms of the measured dissipation rate. On the test dates, weather conditions were calm with wind speeds less than 5 m s-1 and air temperature of 13.5°C. The passing of a previous storm left a remnant active surface-mixing layer, which was further sustained by convective circulation resulting from latent heat loss to the atmosphere.

RESULTS

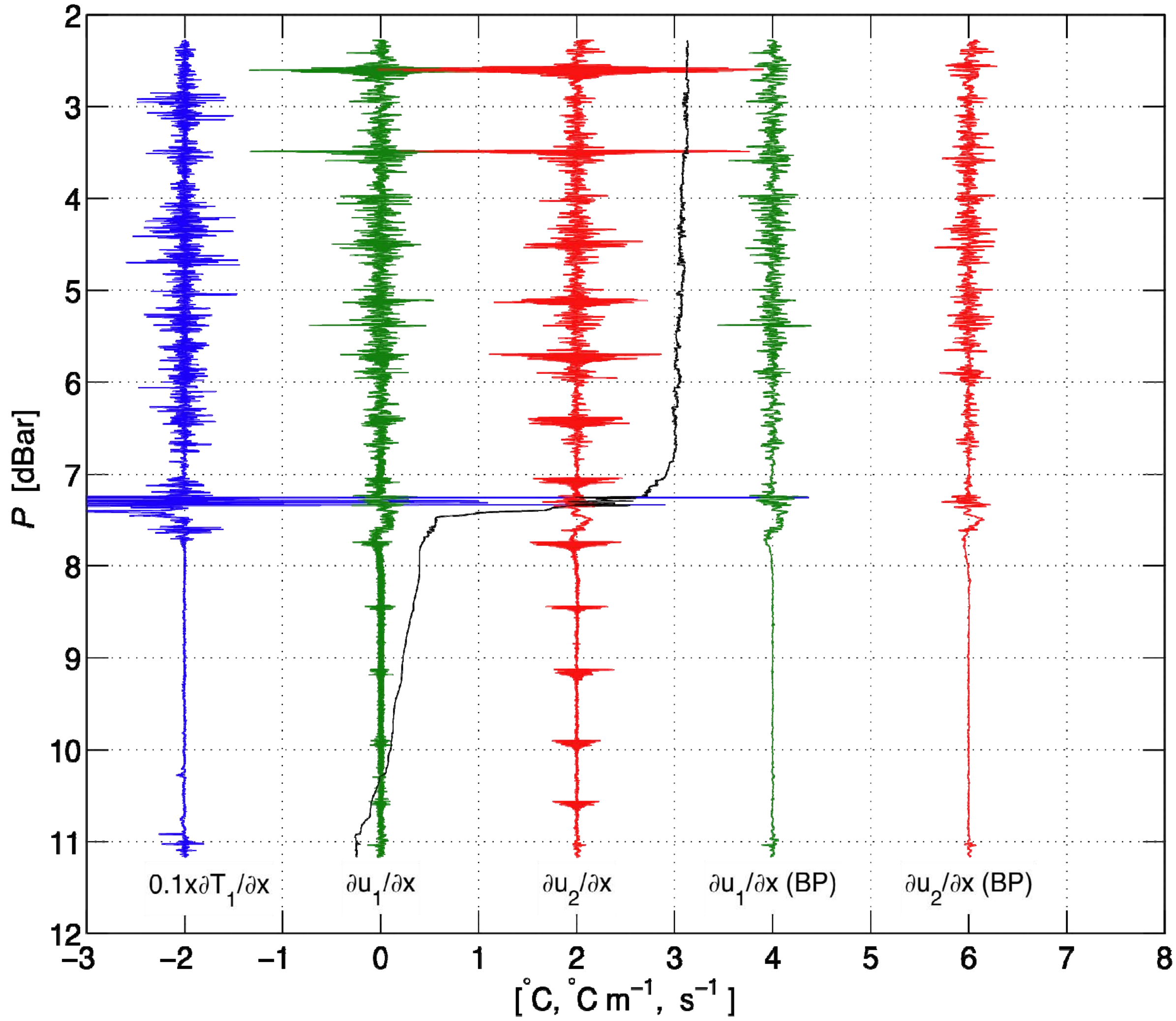

Figure 3: Psuedo vertical profiles of microstructure from Ashumet Pond. Temperature gradient (∂T/∂x) and shear (∂u/∂x) are shown. Shear data were filtered to remove vibrational noise, and the band passed (BP) profiles are shown to the right. The temperature profile, offset left by 10 °C, is shown by the black trace.

Sample data collected during instrument testing are shown in Figure 3. We have presented the data in the form of pseudo vertical profile, taken from an upward trajectory of a saw-tooth gliding cycle. Robust signals of both shear and temperature microstructure were measured, with large turbulence levels recorded above the prominent thermocline. Turbulence levels below the thermocline were very weak. Various sources of vibrational noise are apparent in the microstructure records. These generally occur at low frequencies (the most notable at 1 cycle every 6 seconds), and are outside of the frequency range of interest for dissipation rate estimation. Application of a high-pass filter, and use of the Goodman et al. (2006) algorithm for removing other more subtle vibrational contamination, produces very clean turbulent shear records (right-most profiles, Fig. 3).

Estimates of turbulent dissipation rates were made using both the temperature and shear microstructure records. These show well-defined spectra for both high and low turbulence levels (Fig. 4). The low energy spectrum shows the approximate noise level of the platform's shear-based dissipation rate sensitivity, as limited by both platform vibration and electronic noise. Our estimates suggest a noise level for ε of 2×10^{-11} W/kg, as low or lower than noise levels reported for any microstructure system currently in use.

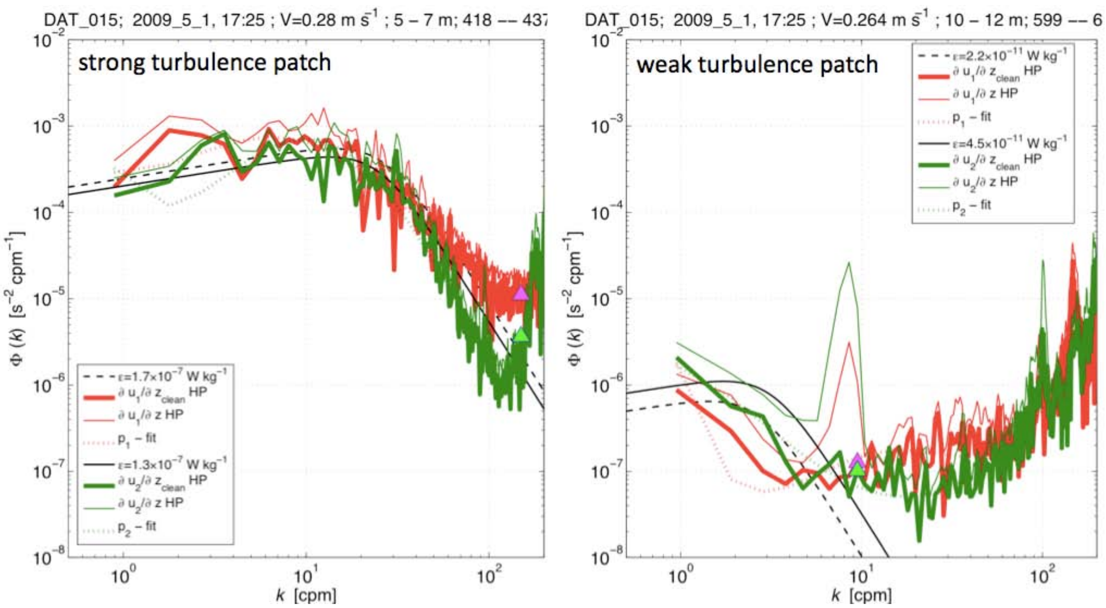

Figure 4: Spectra showing shear dissipation estimates for both a strong turbulence patch (left) and a weak turbulence patch (right). Signals are shown for dual shear probes, with thin lines indicating high passed spectra, and thick lines indication both a high pass filter and use of the Goodman et al. (2006) algorithm. Nasmyth spectra are shown by the dashed lines.

IMPACT/APPLICATIONS

A novel application of the turbulence glider is its capability to measure microstructure through the surface microlayer. This layer is well-defined during calm seas, when breaking wave effects are not present, and the stratification is stable to active convective processes. The microlayer generally extends 20-30 cm below the surface. Given its close proximity to the surface, most oceanographic instruments fail to resolve its structure. The relatively few records of direct measurement are reviewed by Soloviev and Lukas (2006). The properties of the microlayer are fundamentally linked to SST, its diurnal cycle, and the relation of satellite measurements of the sea surface to the subsurface properties.

Direct measurements of dissipation in the surface microlayer are, to our knowledge, non-existent. Turbulence estimates in the surface boundary layer have generally been made using a subsurface measurements of a friction velocity (u*) and then extrapolated to a dissipation profile using the Law of

the Wall scaling relation (e.g. Thorpe, 2006). We believe the turbulence glider will be the first ever means of direct measurement for dissipation in the microlayer.

The glider can measure turbulence on its upward trajectories, collecting data directly to the sea surface. This is facilitated by the placement of the microrider package on top and forward of the glider nose, allowing the microstructure sensors to measure the undisturbed environment ahead of the vehicle. The microrider package measures its own pressure record, directly at the forward end of the package bulkhead about 5 cm behind the microstructure probes. The FP07 thermistors can be calibrated to the Seabird CTD on the glider to give a 1 mm resolution record of temperature through the microlayer, while the pre-differentiated micro temperature and shear records are used in the spectral analysis for dissipation rate estimation.

RELATED PROJECTS

The PI is collaborating with Drs. Steven Jayne, Craig Lee, and Luc Rainville to employ several turbulence sensing gliders during the cold-wake phase of the upcoming ITOP field program. The Slocum system described here will be the only instrument with turbulent shear measurement capability. Several Sea Gliders from APL/UW will be equipped with fast thermistors for measuring microstructure temperature. The Slocum system's deployment will be coordinated with these other glider resources.

REFERENCES

Goodman, L., E. R. Levine and R. G. Lueck, 2006: On Measuring the Terms of the Turbulent Kinetic Energy Budget from an AUV. *J. Atmos. Ocean. Tech.*, **23**, 977–990.

Osborn, T. R., and W. R. Crawford, 1980: An airfoil probe for measuring turbulent velocity fluctuations in water. *Air–Sea Interaction: Instruments and Methods,* L. H. F. W. Dobson and R. Davis, Eds., Plenum, 369–386.

Schofield, O., J. Kohut , D. Aragon, L. Creed, J. Gaver, C. Haldeman, J. Kerfoot, H. Roarty, C. Jones, D. Webb, and S. Glenn, 2007: Slocum Gliders: Robust and ready. *J. Field Robotics*, 24, 473-485.

Soloviev, A. V., and R. Lukas, 2006: The Near-Surface Layer of the Ocean: Structure, Dynamics, and Applications, Springer, New York, 572 pp.

Webb, D. C., P. J. Simonetti, and C. P. Jones, 2001. SLOCUM: an underwater glider propelled by environmental energy. IEEE J. Ocean Eng. 26, 447-452.